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Investing in Software Sustainment

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14. ABSTRACT
In many government weapon systems, sustaining software depends heavily on organic engineering efforts. This is different from hardware sustainment (the more traditional form of sustainment), which often depends heavily on the supply chain and service providers and much less on engineering capability. Because of this shift, a larger portion of sustainment funding needs to be allocated to improving the sustainment infrastructure within government sustainment organizations. This includes the engineering processes, tools, and skills of engineering staff. Failure to recognize this need in a timely fashion has the potential to increase sustainment costs and, at the same time, degrade system performance. The decisions and processes are complex because various stakeholders make decisions at different times, yet these decisions are interrelated, impact one another, and create constraints on the ability of the sustainment organization to fulfill its mission. To deal with the complexity of the decision-making process, the Software Engineering Institute (SEI) developed a simulation model for analyzing the effects of changes in demand for software sustainment and the corresponding funding decisions. The model allows decision-makers to analyze multiple allocation strategies in response to changes from mission command and budget authorities. The model has been tested and calibrated using historical data and is now in operational use by the Process Resource Team at the Naval Air Weapons Station China Lake.

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Investing in Software Sustainment[1]

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Abstract

In many government weapon systems, sustaining software depends heavily on organic engineering efforts. This is different from hardware sustainment (the more traditional form of sustainment), which often depends heavily on the supply chain and service providers and much less on engineering capability. Because of this shift, a larger portion of sustainment funding needs to be allocated to improving the sustainment infrastructure within government sustainment organizations. This includes the engineering processes, tools, and skills of engineering staff. Failure to recognize this need in a timely fashion has the potential to increase sustainment costs and, at the same time, degrade system performance.

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Introduction

The ideas for this model were developed in response to real-world events. One DoD program charged with sustaining a 20+ year old aircraft system asked the SEI how it could justify the capital investment necessary to update its test and support systems and the supply chain. Some of the parts were past end-of-life, making them difficult to source, and the radar—a major technology component—had been updated without updating the test equipment. The situation was placing a major strain on the organization. Engineers had to spend significant work time on eBay buying parts. Radar testing costs escalated significantly because of the new steps required:

1. Remove an airplane from operations.
2. Disassemble the radar to put it in the lab.
3. Calibrate the radar in the lab setting.
4. Complete testing.
5. Reassemble the aircraft with the radar.
6. Recalibrate the radar to the airplane.

Repercussions of this problem will continue even after the equipment becomes available and a new source of parts is established. Both physical plant and process changes will be required to reestablish the level of productivity the organization had when its infrastructure matched the technology requirements of the aircraft systems being sustained.

This type of situation occurs with some frequency and can be summarized as follows:

- An organic sustainment organization with valuable facilities and skills is already in place.
- A new technology makes parts obsolete and leads to new engineering design work.
- The sustainment organization needs to upgrade both skills and facilities to meet the demand.
- While waiting for these changes to be completed, the sustainer's efficiency is compromised, and "mission capable availability" is diminished.
- Until process and tools stabilize, quality often suffers.

Part of the problem for the sustainers is the familiar "color of money" problem; by law, specific funding sources must be applied to specific uses. Funding for product modernization is supplied by the acquisition budget and arrives via the program office. Funding for developing organic sustainment capability typically comes from the life-cycle command function. Delays in funding to update facilities and processes will eventually cause problems in mission performance. Detecting this situation is nearly impossible using spreadsheet analysis alone.

At least five distinct stakeholders are present in sustainment work:

1. Actual operators, who represent the mission-use viewpoint
2. Strategic planners, who review threats to the existing system and opportunities for new system capability based on changes in technology
3. Sustaining engineers, who must address requests for new capabilities as well as addressing the effects of external changes to existing subsystems (e.g., software changes to sensors or communications.)
4. The sustainers' management team, which must invest in facilities and organizational capabilities and retain talent with product domain knowledge
5. The program office, which is responsible for the flow of funds and for promoting the program to all stakeholders

All of the stakeholders have their own definitions of value or utility. Each also has a different timeframe for decisions; hence, each stakeholder may perceive any of the others as delaying the response. The dynamic is one of constant change since technology may change and new threats arise at any time. Figure 1 shows the interaction of the stakeholders and the potential for various gaps in the desired performance.

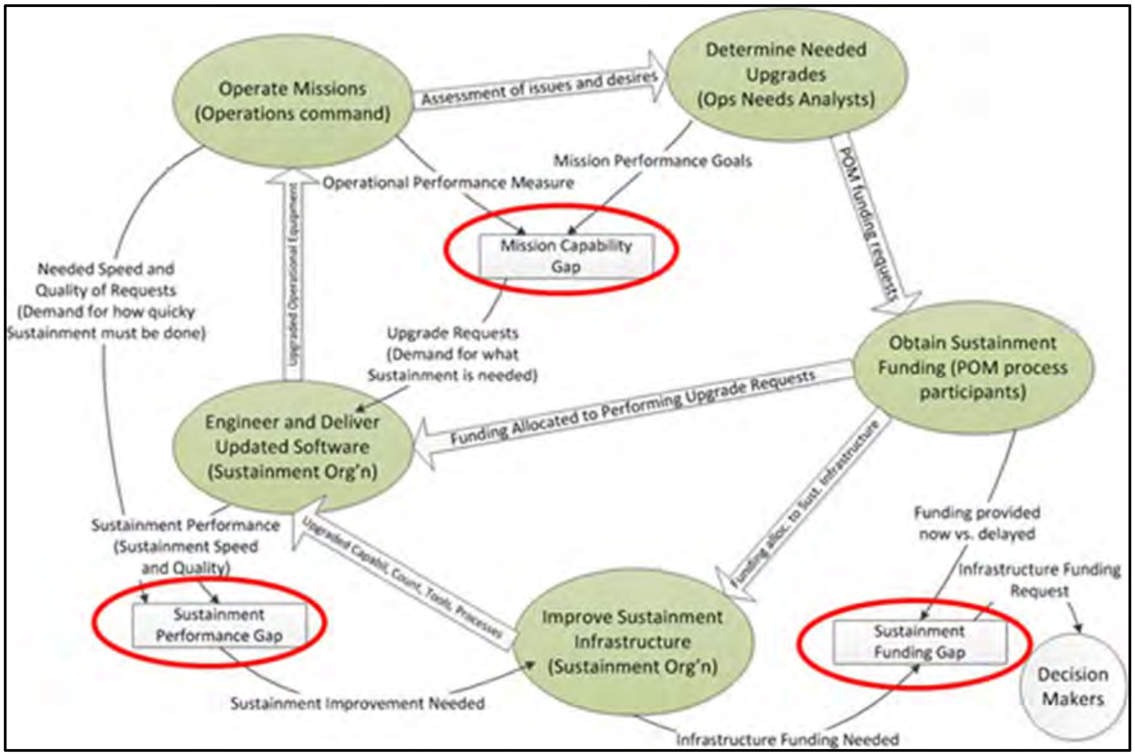

Figure 1. Stakeholders and Gaps

Rationale for a Simulation

Sustainment is part of a dynamic and changing system. Different forces are stronger at different times, and there are time delays between decisions and outcomes that hide valuable information from decision-makers. Any thought of perfect decisions point toward an unattainable ideal. The purpose of the simulation model is to increase the likelihood of better decisions by forecasting several potential futures and examining the consequences. Even if the decision is not optimal at the start, the simulation indicates ways to make course corrections in a more timely fashion.

Simulations use scenarios of input and change to make these forecasts. Each scenario assumes a possible future budget allocation and a future set of demands on both the mission and the sustainer. The simulation then provides a graphical picture of future performance and potential gaps in that performance. In many cases, the simulation will show how a decision that appears sensible at first actually generates a significant performance gap within just a few months. Since some decision cycles are often two years or more, the gap may be one that cannot be overcome in a shorter timeframe than the next decision cycle. This information may be useful in persuading stakeholders (funders) to make different decisions about funding.

The Simulation Tool and Model

The model uses the systems dynamics method described in Peter Senge's (2006) book *The Fifth Discipline*. The SEI's simulation was developed using Vensim and systems dynamics methods (Ventana Systems, n.d.). This type of simulation uses a "stock and flow" model common to systems dynamics (Figure 2).

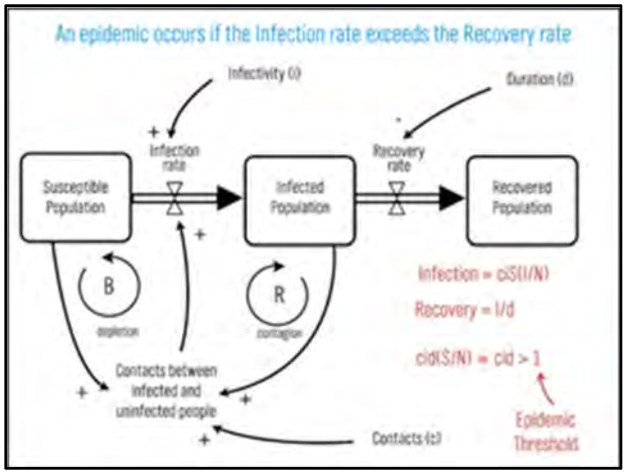

Figure 2. Stock and Flow Model

An epidemic is a good example because the nonlinear behavior and external interactions can create a future dangerous situation. The boxes indicate "stocks" that can be supplied or drained by "flows," represented by double arrows. Stocks may also be initialized. The double triangle is a valve that controls the rate of the flow. The source of a single arrow is a measure. The target is a calculation or control of a valve. If the source of the arrow shows an increasing/decreasing value, the sign +/- implies that the target of the arrow has the same/opposite impact as the measure of the source. In the diagram, an increase in the susceptible population creates an increasing number of contacts. Similarly, if the duration of the infection grows, the recovery rate decreases (the "-").

The full simulation for sustainment is quite large and can be seen in the SEI publication, *A Dynamic Model of Sustainment Investment* (Sheard et al., 2015). A smaller piece showing how technology demands interact with mission performance appears in Figure 3.

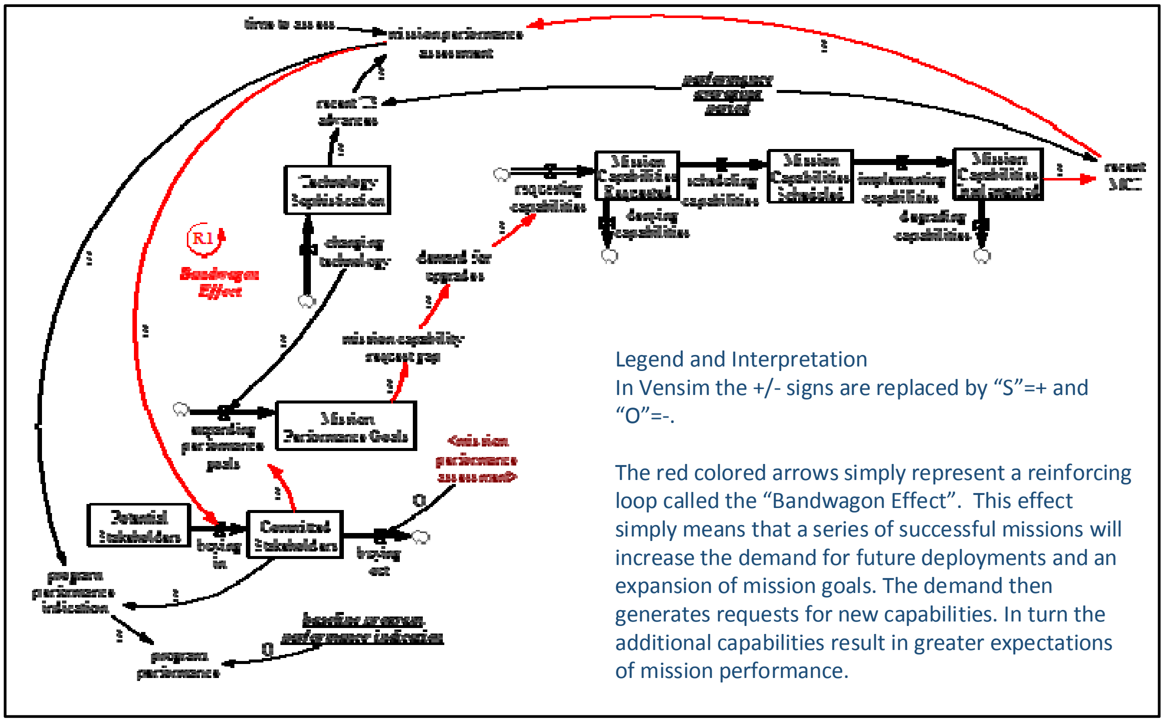

Figure 3. Mission and Strategy Portion of the Simulation Model

The Vensim user interface (presented in Figure 4) provides a customizable control panel with charts and slider bars. The charts show the performance graph of individual variables. The slider bars are a simple control panel for testing different inputs or input equations that drive the simulation. The charts can be selected from any number of available variables in the model. Additional scenarios can be developed to show how actions taken later affect results.

This interface allows decision-makers to use slider bars to set different funding allocation strategies and changes in demand and immediately see the effects of different actions.

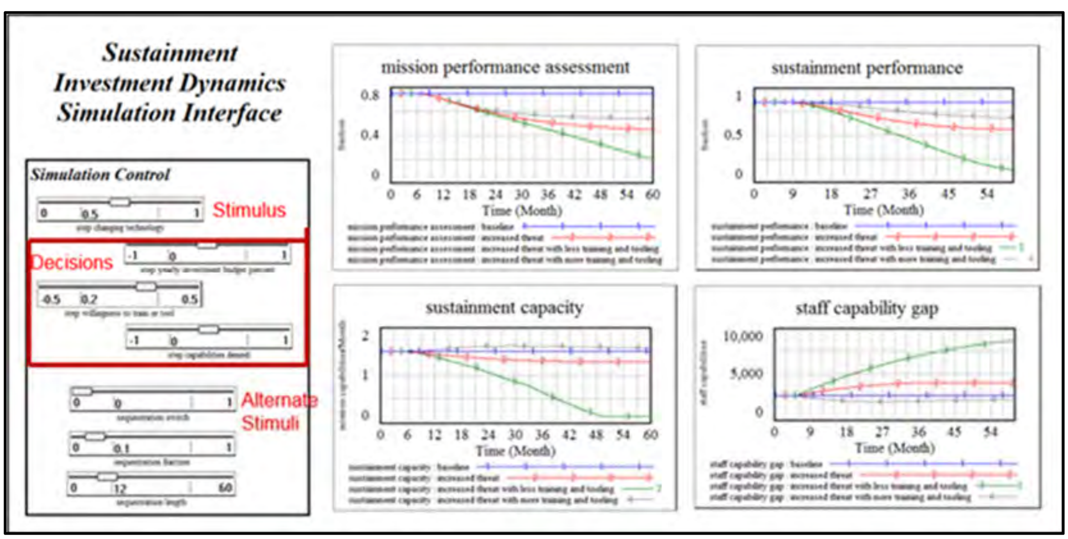

Figure 4. Vensim User Control Interface

Calibration

Calibrating a simulation is always challenging. A model must be simpler than a real-world situation since modeling complete reality is far too expensive and time consuming. Each simplification involves some abstraction from reality, resulting in some redefinition of data. Sometimes an approximation or proxy must be used if real data is not available.

The most common way to calibrate the model is to begin by establishing an equilibrium: When the equilibrium is established, each stock and flow appears constant. This approach works because equilibrium can usually be established by manipulating a smaller subset of the variables and formulas.

A total of 26 flows and 19 stocks are defined in the SEI model. Actual calibration was performed with approximately half the total number of flows and just five of the stocks. The equilibrium values have to be reconciled with data observations of the real system. Two particular assumptions show the complexity of the abstraction:

- **Enhancement Requests:** Every enhancement request was counted as having the same size and effect on the developers. This is clearly inadequate for the longer term viability of the model. Requests come in different sizes—some are big and complicated, and some are much smaller and easier. For improved accuracy, the requests are considered as a set of sizes from very small (VS) to very large (VL).
- **Staff Capabilities:** It was also necessary to connect process capability and organizational capacity. We chose the simple formula:
  Sustainment capacity = A (number of capabilities) * (number of staff),*
  where A is some numeric value that helps to achieve equilibrium when calibrating. This formulation suggests that staff capabilities are closely related to process capabilities, which has been observed in many studies. Proceeding this way, we determined that a capability change could be based on training days, since process changes had to be supported by training days. The stable solution at this time is about 45 days per staff, or about 9,000 total capacity across an organization of 200 people. Capacity is diminished by staff members leaving or reductions in total staff. Improving capacity requires both staff and training employed together.

It is possible that neither of these assumptions will be valid after further study, but the simulation behavior appears acceptable in current use.

Developing Scenarios

Typically, the simulation should imitate real performance and should break where the system would break. Testing the simulation must include running scenarios of change and correlating the changed behavior of the model to the organization’s behavior. A scenario can be described using the elements in Table 1.

Table 1. Scenario Example

ELEMENT	***EXAMPLE***
Scenario name and short description	New mission threat
Context of operation	Normal sustainment activity with a steady rate of enhancement requests
Stimulus	Aircraft squadron runs a normal mission to destroy anti-aircraft capability. However, opponent develops new (technology) capability to detect aircraft.
Response (or decision)	Mission planners request new technology for aircraft mission package to reduce ability to detect airplane. This additional work places a strain on the sustainment organization's ability to deliver on time. Overtime is requested at 20% rate to cover additional demands.
Outcome (what the simulation tells us)	Productivity declines over time anyway.

Additional scenarios can be tested simply by changing any of the first three elements. For example, adding test equipment represents a potential response. Operating during wartime is a new environment. Finally, an example of a new stimulus would be an enemy's new capability to detect a stealth aircraft. Similar scenarios may be generated by any input, whether from customer demand, operational performance, or sustainment performance. Each new scenario may have different effects on the various outcomes in terms of productivity, customer satisfaction, and the ability to perform missions.

Results

Four distinct scenarios were tested during the research. The results of the "Sequestration" scenario are described in this section.

In sequestration, the stimulus was a 20% cut in funding. The initial response was to cut 100% of the training budget. The outcome for that particular response was a steady decline in productivity for as long as sequestration lasted. An alternate response was also considered: maintain training and increase investment in process improvement. The alternate response demonstrated a short-term, six-month loss in productivity but showed higher levels of productivity within 12–18 months. Obviously, there are practical limits to improving productivity, but the model assumes that the capital investment is wisely spent.

Figure 4 also illustrates the possibility of considering alternatives based on changing assumptions about either the baseline or the stimulus event (represented by the box labeled "Alternate Baselines").

The other three scenarios we investigated, which are described in the larger paper, were

- Gating the demand: The sustainment organization chooses to deny a number of requests because it does not have the capacity to fulfil them all. What will it do to sustainment performance and to the mission performance assessment?
- New threat, no budget: An opponent develops a technology that could compromise mission performance. The system is upgraded, but there may not be money for training and tooling. How long does it takes for mission performance to decline and by how much?

- Underfunding sustainment investment: Underfunding occurs when the sustainers are made responsible for the support of a new technology, but there is no budgetary provision to support tooling, process changes, and staff training. Will this affect mission readiness, and how long will it be before the results are observed?

These initial scenarios are not completely independent. “New Threat” proved to be very similar to “Underfunding.” The advantage of documenting the scenario carefully is the ease with which different scenarios can be tested.

Outcomes and Future Work

The Process Resource Team and the Naval Air Weapons Lab worked with the SEI on this model. Their confidence in the model was sufficient enough for them to purchase Vensim and to seek a longer term relationship with the SEI to study and improve the model.

Several kinds of improvement to model are possible. The most obvious is to improve calibration, which will require some additional data. In particular, concepts associated with mission capability, mission performance, and demands for new capability need more precise definitions and better measurement data. Another abstraction that should be reconsidered would address potential trades between process capability and individual capability. The initial model assumes these are the same measure.

The Naval Air Weapons Lab plans to extend the use of the model to other programs within NAVAIR. The future practicality of the simulation model depends on both our ability to calibrate the model to the system of interest and whether the scenarios tested represent actual experience. In any case, the simulation will almost certainly help the organization develop better long-range plans and improve cost and schedule risk mitigation.

References

Senge, P. M. (2006). *The fifth discipline: The art & practice of learning*. New York, NY: Crown Business.

Sheard, S., Ferguson, R., Moore, A., & Phillips, M. (2015). *A dynamic model of sustainment investment* (CMU/SEI-2015-TR-003). Retrieved from the Software Engineering Institute, Carnegie Mellon University website: http://resources.sei.cmu.edu/library/asset-view.cfm?AssetID=433454

Ventana Systems. (n.d.). Vensim. Retrieved from http://vensim.com/

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